Structural Damage Identification in Wind Turbine Blades using Piezoelectric Active Sensing

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Remarkable advances have been achieved in the wind turbine industry with the development and implementation of modern technology. This significant improvement in wind turbines is motivating manufacturers to produce more efficient, yet complex, wind turbines. The trend in wind energy is also toward larger, longer (>50 m), and heavier (>7 tons) blades in order to generate more power. Ensuring the reliability of wind turbine design is one of the most important aspects in enhancing safe and proper operation.

It has been reported that monitoring the structural health of the turbine blades requires special attention as they are key elements of a wind power generation, and account for 15-20% of the total turbine cost. Recent studies indicate that blade damage is the most expensive type of damage to repair and can cause serious secondary damage to the wind turbine system due to rotating unbalance. Composite materials are widely used in wind turbine blades because of their lightweight and high strength. The use of composites, however, leads to various types of failure modes including delamination, fiber breakage, matrix cracking, waviness, and fiber-matrix debonding. Delamination appears to be the most frequent failure mode, usually caused by imperfect fabrication, cracks in matrix materials, impact by foreign objects, or other hazardous service environments. Delamination substantially reduces stiffness and buckling load capacity which, in turn, influences the structure's stability characteristics.

In this project, therefore, we will explore several structural health monitoring (SHM) techniques based on the novel use of piezoelectric active materials. Piezoelectric materials are very useful in SHM because they can perform both duties of sensing and actuation within a local area of the structure. Piezoelectrics are a class of materials in which there is a coupling between mechanical and electrical domains. Therefore, this type of material generates mechanical strain in response to an applied electric field. Conversely, the materials produce electric charges when stressed mechanically. This coupling property allows one to design and deploy an "*active*" and "*local*" sensing system whereby the structure in question is locally excited by a known and repeatable input, and the corresponding responses are measured by the same excitation source.

Three techniques, including Lamb wave propagation, frequency response functions (FRFs), and impedance-based methods, will be integrated and used to interrogate the sections of wind turbine blades in this project. In Lamb wave propagations, one piezoelectric acting as an actuator generates an elastic wave through the structure, and responses are measured by an array of piezoelectric sensors. The changes in both wave attenuation and distortion will be used to detect and locate damage. The impedance-based and FRF-based methods monitor the variations in structural mechanical impedance, which is coupled with the electrical impedance of, or FRF measured by the piezoelectric transducers. These techniques operate in the high frequency ranges (typically > 30 kHz) at which there are measurable changes in structural responses even for incipient damage, such as small cracks, and debonding.

The main focus of this project will be assessing and constructing a performance metric for each method to compare the performance of each SHM technique in identifying incipient damage. We will use a 1m test sample cut from a 9m CX-100 experimental blade, fabricated with techniques commonly used in wind industry. In order to validate the capability of SHM techniques, the results of ultrasonic scanning will be used for verification purpose. Furthermore, the project will also investigate the effect of local damage on the global response of the blade by monitoring low-frequency response changes.

SCHEDULE

Weeks	Tasks
1	Orientation
2	Background research on the topics of piezoelectrics and papers listed below
3	Installation of piezoelectric patches to honeycomb panels. Hardware use orientation.
4	Vibration testing/modal analysis of the structure with accelerometers and PZT sensors
5-7	Experimental investigation using Lamb wave propagation, impedance methods, FRF. Data analysis
8	Begin write-up, reiterate tests, codes, etc as needed.
9	Writing up of results and presentation

HELPFUL REFERENCES

1. Park, G., Sohn, H., Farrar, C.R., Inman, D.J. 2003. "Overview of Piezoelectric Impedance-based Health Monitoring and Path Forward," *The Shock and Vibration Digest*, **35**(6), 451-463.
2. Sohn, H., Park, G., Wait, J.R., Limback, N.P., Farrar, C.R. 2004. "Wavelet-based Signal Processing for Detecting Delamination in Composite Plates," *Smart Materials and Structures*, **13**(1), 153-160.
3. Hay, T.R., Wei, L., Rose, J.L., 2003. "Rapid Inspection of Composite Skin-Honeycomb Core Structures with Ultrasonic Guided Waves," *Journal of Composite Materials*, **37**(10), 929-939.
4. Thien, A., Chiamori, H., Ching, J., Wait, J.R., Park, G., "Active Sensing for Damage Detection in Pipeline Structures," *Proceedings of 23rd International Modal Analysis Conference*, Jan 31-Feb 3 2005, Orlando, FL.
5. Park, G., Farrar, C.R., Rutherford, C.A., Robertson, A.N., 2005, "Piezoelectric Active Sensor Self-diagnostics using Electrical Admittance Measurements," *ASME Journal of Vibrations and Acoustics*, in review.
6. "Innovative Design Approaches for Large Wind Turbine Blades," TPI Composites, Inc., Project Report for SNL, SAND2003-0723, March 2003.

7. Ashwill, T.D., “Some Recent Trends & Activities in Turbines and Blades,” Sandia National Laboratories 2nd Wind Turbine Blade Workshop, April 2006.
8. Ciang, C.C., Lee, J.R., Bang, H.J., “Structural Health Monitoring for a Wind Turbine System: A review of Damage Detection Method,” Meas. Sci. Technol. 19 (2008), 122001.
9. TPI Composites, *Innovative Design Approaches for Large Wind Turbine Blades; Final Report*, SAND2004-0074, Sandia National Laboratories, Albuquerque, NM